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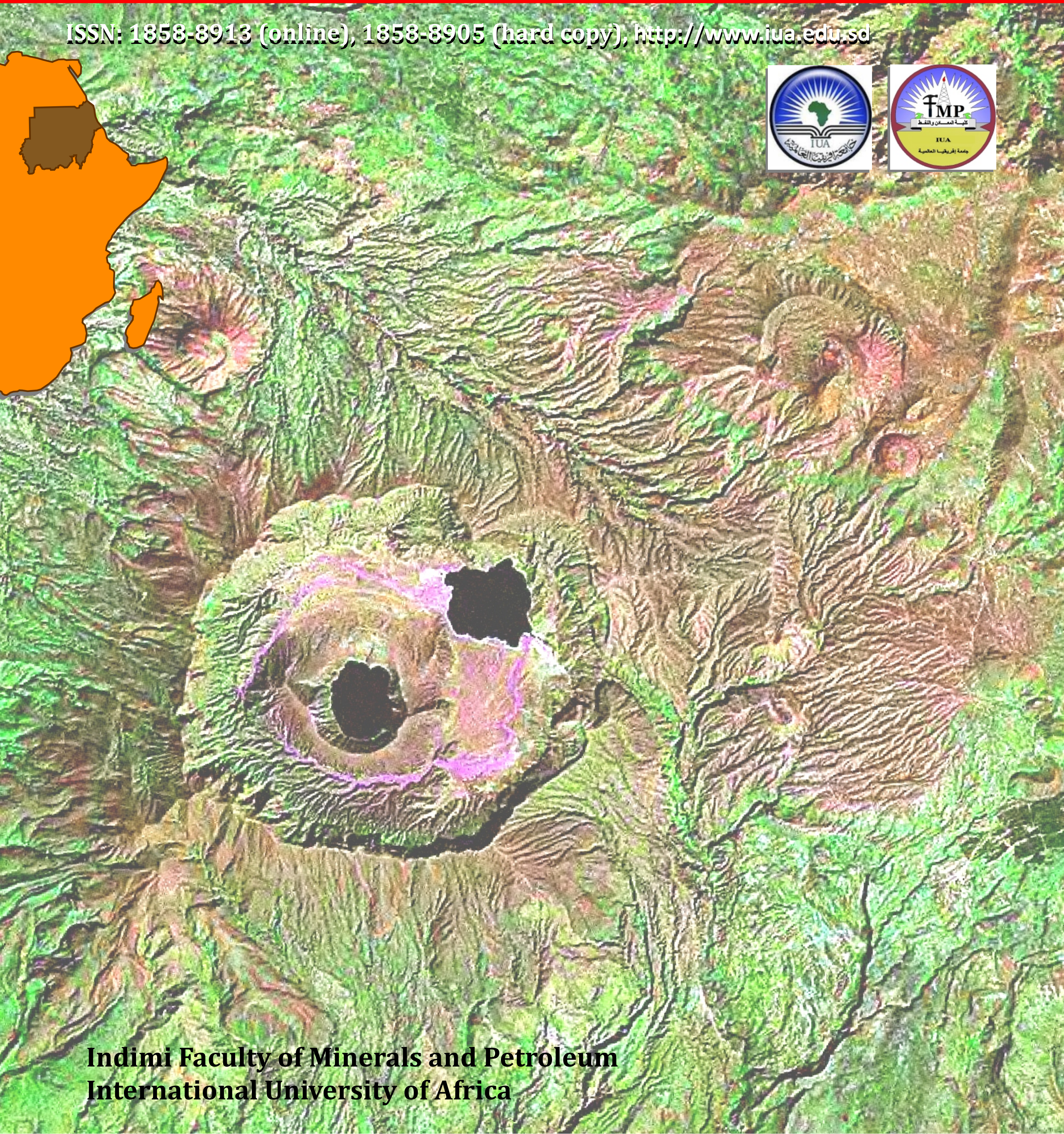

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مجلة علمية محكمة

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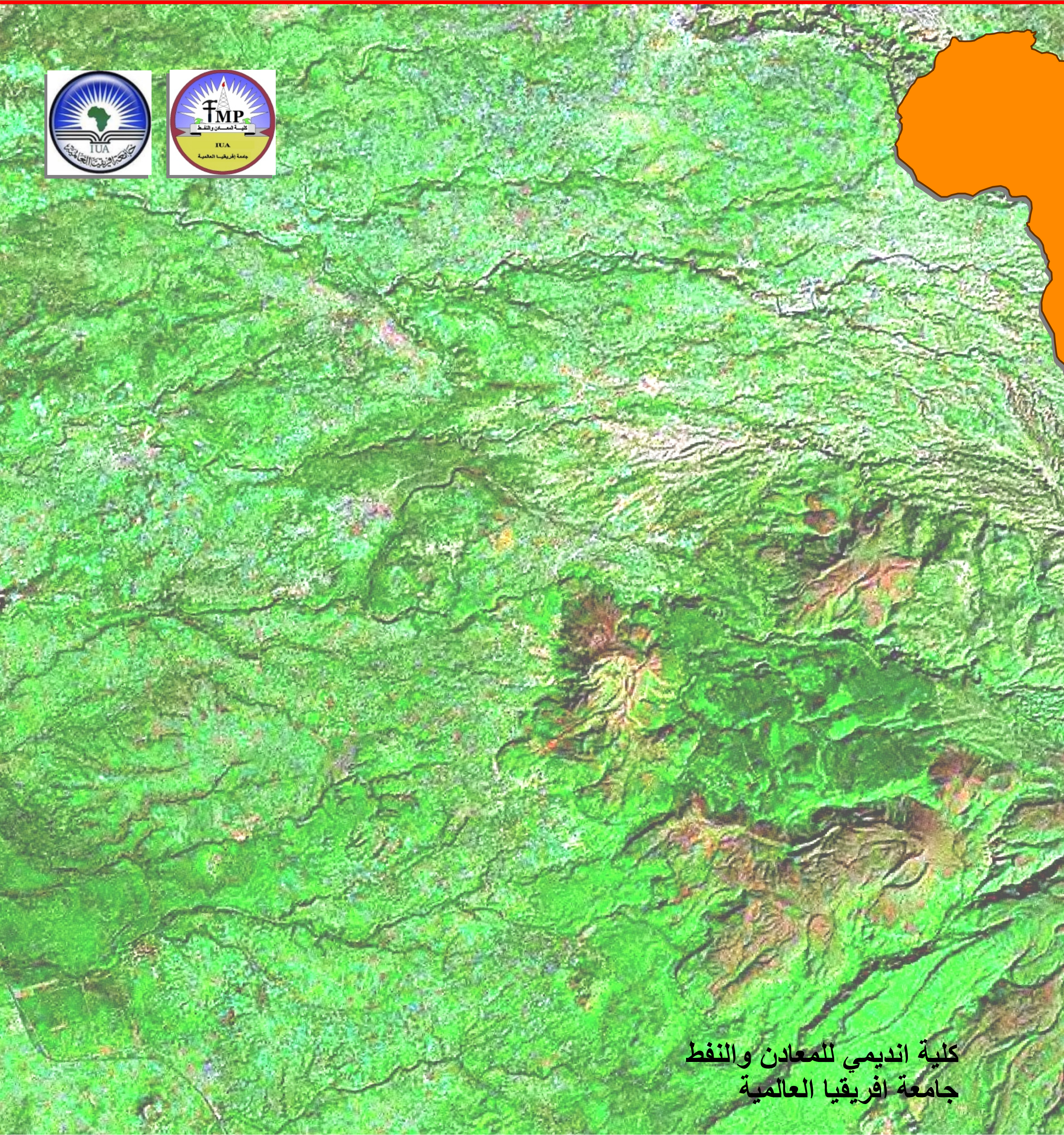

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Design Criteria and Evaluation of Relief Wells in Rosaries Dam Heightening Project, SE Sudan

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Abstract

The study area comprises of Rosaries dam in the Blue Nile State in southeastern Sudan. The dam had been constructed above pervious layer confined between two impervious layers and this gave rise to hydrostatic pressure under the dam elements. The objectives of the study were to evaluate the present situation of relief wells in the Rosaries dam heightening project, to state and discuss optimum measures and characteristics of well design criteria of relief wells and borings and to document for profession experience in this scope of work in Sudan. The study has adopted descriptive and analytical methods which made use of previous data provided by dam implementation unit and complemented with data collected during field visit which included drill logs of wells, daily and annual reports of relief wells and borings, laboratory result of sieve test for gravel pack and aquifer materials and photographic slides. Data were processed and analyzed using Microsoft Office Excel, Rockworks15 and Auto CAD programs. The geotechnical site investigation showed that the vertical geological succession consists of pervious strata with high to moderate permeability confined between two impervious layers. This stratigraphic and lithologic setting gave rise to high hydrostatic pressure under foundations of the embankment during reservoir impounding; which threatened the stability of the dam embankments. Water level was monitored in the relief wells before and after impounding showed that all relief wells in the two embankments are working effectively and successfully. The study has recommended for monitoring and maintenance of the concrete shaft of the relief wells including secure cover and water level measurement. It also recommended for making periodic inspection, maintenance and rehabilitation for the relief wells.

Key Words: Embankment, Hydrostatic pressure, Relief wells, Rosaries dam, well design,

1. Introduction

All water retention structures are subject to seepage through their foundations and abutment. In many cases the seepage may result in excess hydrostatic pressures or uplift pressures beneath the hydraulic structure or in the downstream area. This perhaps the construction is above permeable layer confined between two impervious geological strata.

This study will provide some insights and information on how the hydro-geological problems in civil engineering project particularly dams' construction are solved by installation of relief wells and boring decrease the hydrostatic pressures and uplift pressure to a minimum. On the other hand, the significance of this study is coming from the fact that it is the first conducted research in Sudan which deals with design, construction and evaluation of the relief well.

The first use of relief wells to prevent excessive uplift pressures at a dam site was carried out by the US Army Engineer District, Omaha, when 21 wells were installed from July 1942 to September 1943 as remedial seepage control at Fort Peck Dam, Montana (Middlebrooks, 1948). The foundation consisted of an impervious stratum of clay overlaying pervious sand and gravel. The first surface evidence of the high hydrostatic pressure came in the form of discharge from an old well casing that had been left in place**.** The relief wells were installed to provide a measure of safety with respect to uplift and piping along the downstream toe of the embankment. Since these early installations, relief wells have been used at many levee locations to control excessive uplift pressures and piping through the foundation (US Army Engineer Waterways Experiment Stati 1958) (U.S. Army

Corps of Engineers, Engineering Manual 1110-2-23000, (30, July 2004).

In Sudan relief wells had been used in Roseires Dam in 1966, designed to higher water level elevation of 483m amsl with an allowance to be raised by 10m. A number of 207 relief wells were installed in the embankments, (RDHP, 2009). In the Marawei dam in 2009, where 19 temporary relief wells on the coffer dam to realized the hydrostatic pressure and decrease the water level during construction of the earth concert rock dam (ECRD, 2006). Also relief wells were installed in the dam complex of Upper Atabra project, where 23 relief wells were installed on the right bank.

The study area - Roseires dam - is located in the Blue Nile State in southeastern part of Sudan, upstream of Ed-Damazin town, capital of the State. The State is bounded between latitudes 9º 30′ and 12º 30′ north, and longitudes 33º 5′ and 35º 3′ east. It has an area of 45,844 km². The area of the study is accessible from Khartoum by various means of transport, the asphaltic road (Khartoum-El Damazin) which is 550km long and by air from Khartoum to El Damazin airport (Figure 1 location map). The first stage of the Roseirs dam was to elevation of 483m amsl with reservoir capacity of 3 billion cubic meters which was completed in 1966. The second stage of heightening 10m to elevation of 493m amsl was completed in 2013, with a reservoir capacity of 7.4 billion cubic meters (RDHP, (2009). Report on geotechnical site investigations for concrete buttress dam. Sudan.).

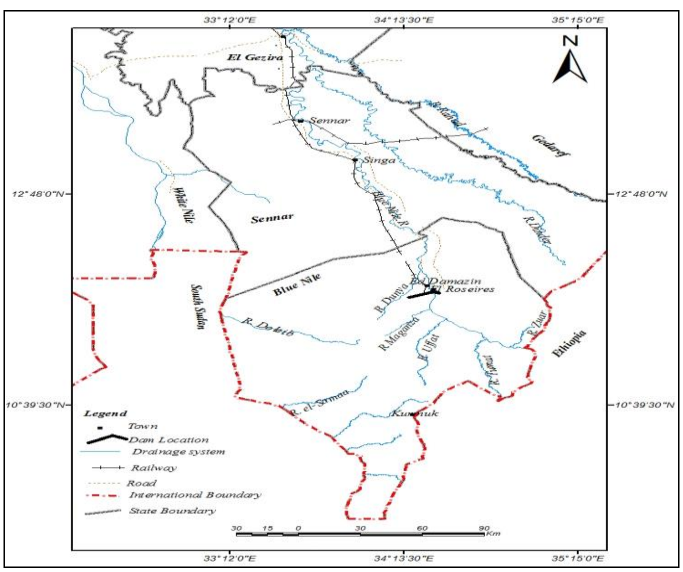

Fig. 1. Location map of the Rosaries dam heightening project

The Blue Nile rises in the volcanic plateau of Ethiopia it has cut down through a massive sequence of basalts to form deep gorges in its track to the Sudanese border. Beyond the border the terrain becomes much more subdued and the eroded material is deposited to form vast tracts of alluvial sediments that extend all the way along the course of the Blue Nile to Khartoum. The alluvium is more sandy and gravelly near the border and becomes more clayey as it forms the extensive Gezira clay plains beyond Sennar (Williams and Adamson, 1973). The whole of the eastern region, roughly demarcated by the international frontier, comprises ground above 1000m amsl which forms the dissected limits of the Abyssinian highland. The western plains lie below 500m amsl, and between is a rough, rocky terrain (Vail, 1986). The Qeissan area in the southeast lies within an undulating landscape, the base level rises to about 600 to 700m amsl; Jebel Furunge is the highest elevation in the area (Siddig, M. E. and Ahmmed H. E., 2013).

The southern Blue Nile region is characterized by both flat clay plains and a hilly topography in the south and the southwest, with gentle slopes towards the north and southeast. There are pediments that are gently sloping and with drainage flow connected to the Blue Nile River system

The construction area of the Roseires dam is divided by the Blue Nile River valley with outcrops of rock forming the rising river slopes from elevation of 450m to elevation of 470m amsl. The land in the eastern bank of the study area reaching the level of the heightening dam crest at the 8.5km from the Blue Nile and 15.5km in the western bank, generally the topography of the study area is shown in Figure, 2.

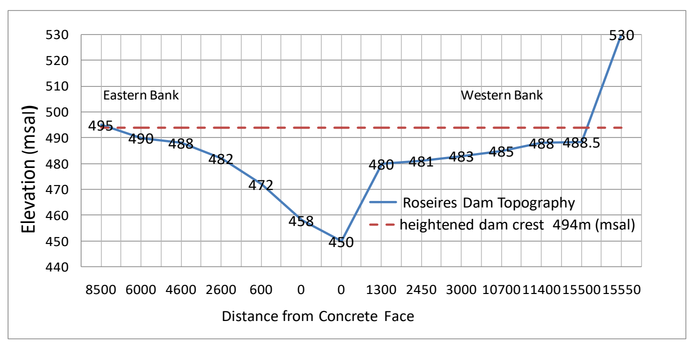

Fig. 2. Topography sketch along Roseires dam heightening project area.

The study area lies in the rich savannah climatic zone, which is characterized by high temperatures and heavy rainfall. Temperature is generally high through the year, ranging from a daytime average of 26ºC in January (winter) to 32ºC in April (summer). The dry season extends from November to April while the rainy season extends from May through October; annual rainfall average is around 700mm (OCHA Sudan).

The study area is regarded as one of the richest forest and grazing land in the Sudan, covered with scattered *Acacia mellifer* (Kiter), *Acacia Seyal* (Taleh), *Balanites Aegyptica* (Hegleg) and *Cyperus papyrus* (Haseer).

The geotechnical site investigation in RDHP shows that the vertical geological sections of the site consists of silty sand and sand which is confined between two impervious layers of clay or clay and bed rock, this will give rise to high hydrostatic pressure and uplift pressure on the confined aquifer under foundations of the embankments and this may threaten the embankment dam stability. To prevent seepage, uplift and piping, relief wells and relief boring were installed to provide an added measure of safety. In this context the present study is aiming at the following objectives

- To evaluate the present situation of relief wells in the RDHP.
- To state and discuss optimum measures and characteristics of well design criteria of relief wells and borings.
- To document for profession experience in this scope of work in Sudan

2. Geology

The bedrock at Rosaries dam area is made up of a varied assemblage of metamorphic and igneous rocks that form part of the basement Complex of the Sudan. It comprises of the following units:

2.1. Biotite gneiss: Occurr throughout the area as the lower basement unit; the rock is medium to dark grey, banded or foliated with separated layers of quartz,feldspar, biotite and/or hornblende.

2.2. Granitic gneiss and migmatite: Essentially intercalated with the biotite gneiss and also forming some distinct zones. It is composed mainly of quartz and alkali-feldspar and lesser plagioclase with spotted clusters of biotite.

2.3. Pegmatite and aplite dykes and veins: Occurring both as early intrusions into the gneiss and also as late stage intrusions cross cutting the Late Granite. The pegmatite has a granitic composition, and is coarsely crystalline whereas the aplite is characteristically consisting of quartz and feldspar alone, without biotite and mostly occurs as planar veins.

2.4. Late-tectonic granite: This rock unit name is used by Knill and Jones (1965), to denote that it is younger than the other rock units. It is unfoliated and uniformly crystalline and composed of quartz, alkali feldspar, plagioclase, biotite and minor muscovite.

2.5. Superficial deposits: They are generally Nile silt, gravel, sand and black cotton soil. The east banks covered by light brown sand with lenses of dirty sand and highly fissured surface light brown or brownish grey clay with calcareous material. The thickness of the superficial deposits ranges between 0 and 20m. The west banks covered by light brown to brownish gray and dark gray clay and lens of light brown sand. The thickness of the superficial deposit range between 5 to 20m.

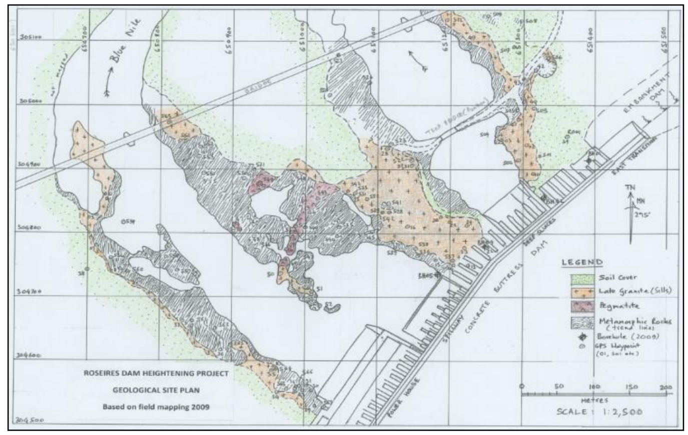

Fig. 3. Geological map of the dam downstream area (RDHP, 2009).

3. Methodology

Fieldwork has included site visits to RDHP for four days during September 2015. During this period of time site visits and inspection of relief wells on the eastern embankment and western embankment were conducted to check for the efficiency and condition of the wells. Water level measurements were carried out in addition to taking photograps at different locations. Post field phase has included sorting out, classification and analysis of data collected in the previous phases. Both laboratory analysis and computer based analysis were carried out. In the computer based analysis Auto CAD and Rockware 15 computer program were used for drawing of vertical geological cross-section. grain-size was carried out to classify the soil and calculate sediments parameters.

4. Results and discussion

4.1. Subsurface geology

Geological cross sections along the western embankment were derived from geological logs of the relief wells and relief boring of line one from closed to the river up to D+720 m. The black cotton soil cover is range between 0 to 8m and the solid rock is observed between 8 to 13m below design elevation (BDE) of the relief wells line 1, at D+840 the thickness of the black cotton soil vary from 1 to 6m the weathered rock observed at 7.8m. In the geological section from D+865 to 4025m the soil profile is BCS of thickness ranges between 1.5m and 8.36m. Geological cross section from D+ 10724 to 15500m is similar to the previous one with an increased black cotton soil layer thickness which is 5 to 8 m. The black cotton soil is underlain by silty sand layer. Towards the end of the embankment alignment the bedrock surface rises and is encountered at 10m deep, where the alluvial plain abuts the rising hill of marble at D+15,200.

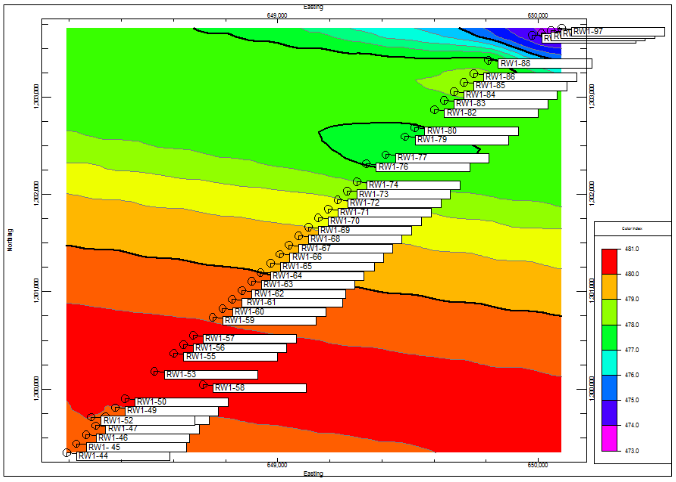

Fig. 4. Location of relief wells (LB) from Rw1-97 at D+ 965 to Rw1-44 at D+ 5725

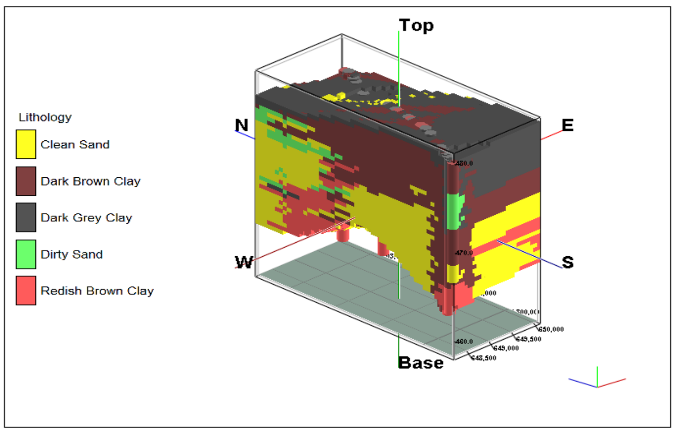

Fig. 5. Block diagram (LB) from Rw1-97 at D+ 965 to Rw1-44 at D+ 5725

4.2. Lithological characteristic of sand lenses

Results of grain-size analysis according to BS 1377-2 and field description the dirty and clean sand in the western embankment are described as follows.

Poor graded sand, in the relief well No. Rw1-1, in the field described as "sand, brown to whitish, medium to coarse". The laboratory sieve analysis test according to British Soil Classification system (BSCS), BS 5930-1981, relief well No. Rw1-1, described as poorly graded sand.

Well graded sand, in the relief well No. Rw1-5, in the field described as "sand, fine to medium". The laboratory sieve analysis test for RW1-5, described as well graded silty sand or well graded clayey sand.

Silty sand, in relief well No. Rw1-13, in the field described as sand, fine to medium. Whereas from sieve analysis results, is described as silty sand or clayey sand.

Generally, most of sand lenses of the aquifers are poorly graded sand with silt or clay with high to moderate permeability, for more examples see Figure 6.

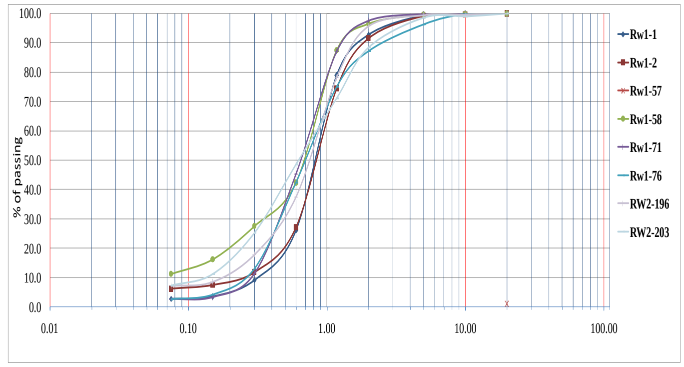

Fig. 6. Example of grain size distribution of sand lenses (aquifers) LB.

4.3. Hydrogeological characteristic of the study area

There are four water bearing layers in the western embankment, as follows:

1. Silty sand formerly known as dirty sand.
2. Clean sand
3. Weathered basement rocks
4. Fractured basement rocks

A confining layer of clay materials overlies these layers giving rise to a confined aquifer condition. There are 9 sand lenses encountered along left embankment. The confined aquifer under the embankment of Roseires dam are in hydraulic interconnection with the dam water reservoir with high water level in the reservoir artesian peizometric head will occurs in these confined sand lenses which might reduce the stability of the dam. To prevent this effect, the artesian water pressure has to be relieved by special relief wells constructed along the downstream.

During impounding in 2013, groundwater levels fluctuation measured in the relief wells in line 2 along the western bank were as shown in the figure 7.

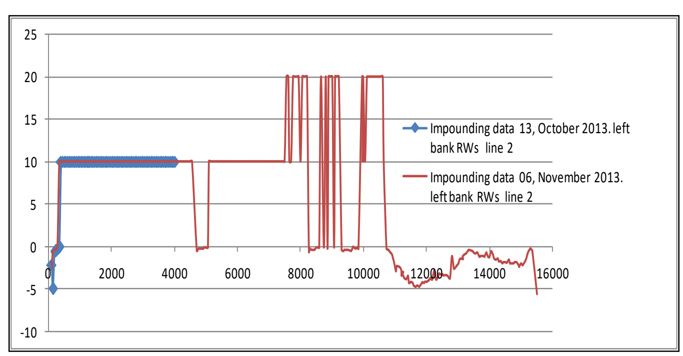

Fig. 7. Water level fluctuation during impounding November, 2013 western LB (The minus reading refer to real value of water level below design elevation of the relief wells).

During and after impounding, the water level in the reservoir increases up to reach the top level of the reservoir (493m amsl), with high water level artesian piezometric head will occur in the confined water bearing layers and this is clear from water level measurement in the relief wells line 2 in the western bank.

See the water level variation through the embankment from D+0 up to D+15500m, the water Colum in the reservoir is 5m minimum and 26m maximum, as shown in the figure 6.

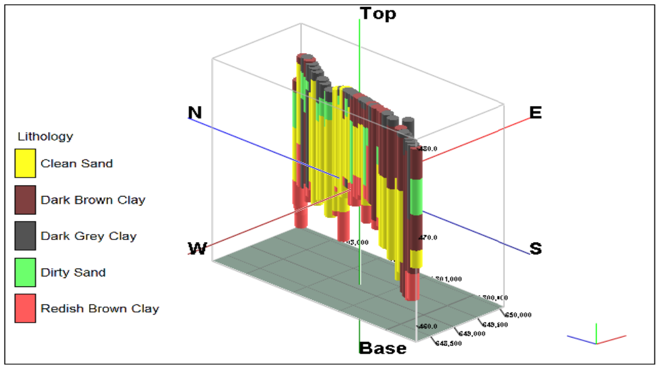

Fig. 8. 3D diagram for strip alog (LB) from Rw1-97 to Rw1-44 on the LB

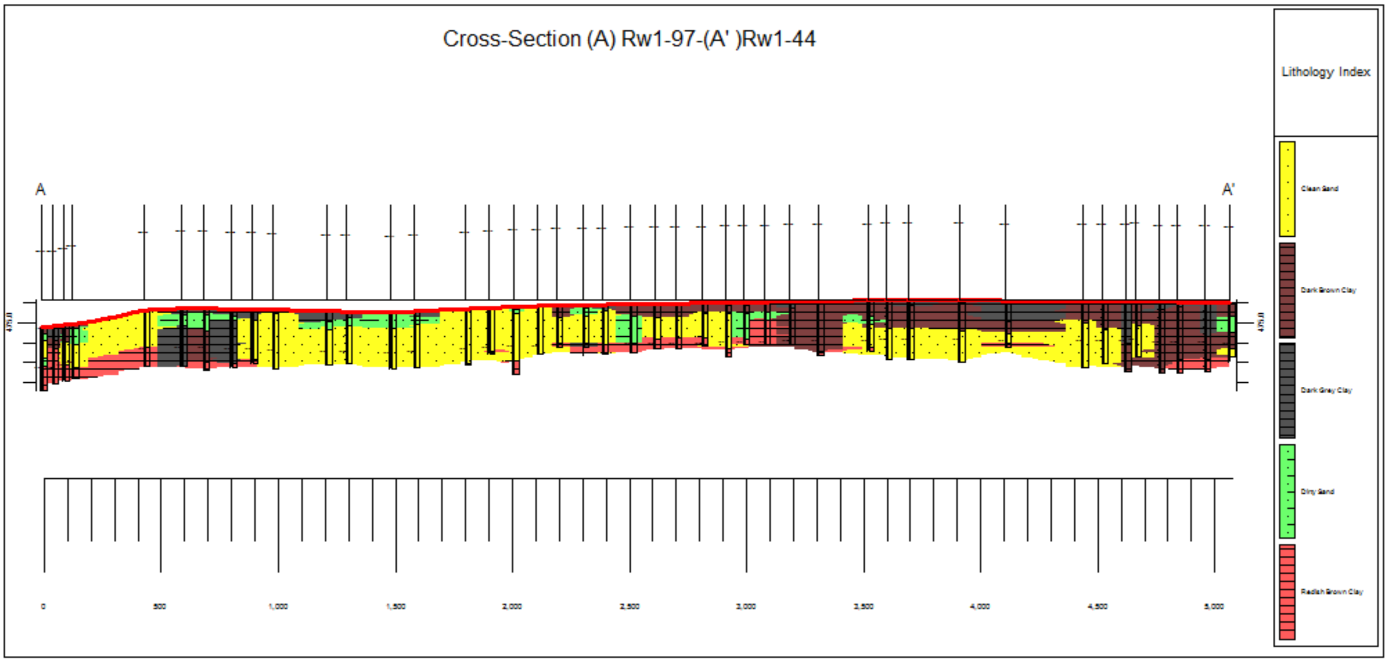

Fig. 9. Vertical geological section (LB) form Rw1-97 to Rw1-44 on the LB.

5. Conclusion

The results presented as vertical geological section obtained from lithological data of relief wells and borings have shown that the dam is constructed over permeable layers confined between two impermeable layers, and not directly connected to the dam reservoir. There are nine sand lenses extending from the river towards the west direction in the western embankment with thickness ranges between 1.9m and 12.9m and between 50m and 500m in length. Those lenses also are not connected together. They consist of very well to poorly sorted with moderate permeability. This geological setting has exerted high hydrostatic pressure under the foundation of the dam. Also from the monitoring of the water level in the relief wells line two in the western bank, before, during and after impounding showed that there is high hydrostatic pressure under the dam foundation. This problem is solved by construction of the relief wells and borings. On the other hand, the study showed that all relief wells in the western bank are performing successfully and effectively.

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